BUREAU OF ENGINEERING
of the
DEPARTMENT OF PUBLIC WORKS
CITY AND COUNTY OF SAN FRANCISCO
CALIFORNIA

Hetch Hetchy Water Supply

By

M. M. O'SHAUGHNESSY
Member American Society, C. E.
CITY ENGINEER, SAN FRANCISCO

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HETCH HETCHY PROJECT

Foreword

The past three years have been marked with strenuous activity toward the completion of the Hetch Hetchy Water and Power Project of San Francisco, which will be capable of furnishing the water supply for a population of 4,000,000 people when the construction storage works in the high Sierras have been completed.

Five key dams stand completed, two of which—the O'Shaughnessy Dam and the Lake Eleanor Dam, hold back an aggregate amount of water greater than all the reservoirs of Los Angeles and San Diego massed together.

Twenty miles of aqueduct tunnels have been completed in the high Sierras, while at the westerly end of the project Spring Valley water is being passed since September 12, 1925, through the Bay Crossing Aqueduct, 22 miles in length. The right-of-way for the aqueduct measures the width of the State and over this right-of-way the transmission towers have been erected which carry electric energy from the Moccasin Power Plant to the gates of San Francisco.

Since August 14, 1925, the Moccasin Power Plant has been put into service and is now furnishing the greater portion of the power used to light the homes of San Francisco and drive the wheels of its factories. This has been made possible through a contract entered into with the Pacific Gas & Electric Company under which that company is employed as the temporary distributor of San Francisco's power output. The City received for the power delivered in San Francisco during the month of September, $182,426.97, or at a rate somewhat in excess of $2,000,000 annually. On this basis the net revenue from the power, after paying operating expenses, and the $250,000 per annum to be received from the Spring Valley Water Company for the temporary use of the Bay Crossing Aqueduct, amounting to $1,900,000, will pay the interest at 4½ per cent on $42,000,000 of bonds, which is more than is now outstanding on the entire project.

The gap remaining to be completed in the water supply portion of the project is the tunneling and laying of pipe from Moccasin Power House, through the mountains that mark the San Joaquin, Livermore and Santa Clara Valleys, to Irvington terminal. The work in the Foothill Division is now actually under way.

The purpose of this outline is to enlighten the public generally concerning this water and power project, which is the greatest asset that San Francisco possesses, and to these this report is respectfully submitted.

M. M. O'SHAUGHNESSY,
City Engineer.

San Francisco, California, October, 1925.

HISTORY OF HETCH HETCHY WATER SUPPLY

By M. M. O'Shaughnessy, *City Engineer*

EARLY SOURCES OF SAN FRANCISCO'S WATER SUPPLY

SAN FRANCISCO'S earliest water supply was taken from wells within the City, and ten million gallons daily are still obtained from this source. Such wells, however, soon became inadequate, and for a time it was necessary to import additional water in barges from across the Bay, and to distribute it by means of water wagons.

In 1858, a company known as the San Francisco Water Works, instituted a pressure pipe water service, the source being Lobos Creek, which drains the northwesterly portion of the present City. A second company, the Spring Valley Water Works, brought water three and one-half miles from Islais Creek in 1861, and the following year increased its supply by taking from Pilarcitos Creek, 32 miles away. The two companies combined in 1865, under the name of the second, which, in 1903, reorganized as the Spring Valley Water Company.

Under the single management, the sources were gradually added to; San Andreas and Crystal Springs reservoirs in San Mateo County were constructed, and pipe lines were built connecting them to the City.

The Peninsular supply was added to in 1888 by the completion of two submarine pipe lines crossing San Francisco Bay and bringing in water from Alameda Creek. The capacity of the pipe line was increased in 1902, and a booster pumping station added in 1913, bringing the present Spring Valley yield capacity up to about 42 million gallons daily—twenty million from the Peninsula and twenty-two million from the Alameda County sources.

The Spring Valley Water Company acquired, through all those years, over 100,000 acres of land. After a complete survey in 1915, the City Engineer, with the approval of the Railroad Commission, as a basis for purchase by the City, excluded all but 61,560 acres of land as being necessary for water purposes. In San Francisco County there remains for City use 913 acres, in San Mateo 22,817 acres, Alameda County 24,220 acres, and in Santa Clara 13,610 acres.

On the 17th of April, 1922, an agreemnet, sanctioned by the Railroad Commission, was made between the Water Company and the City for the development of an additional 24 million gallons daily by the Company's reconstruction of the Calaveras Dam, Niles Canyon concrete conduit, and 16,000 feet of 44-inch pipe from Niles to Irvington. The City agreed to spend $5,000,000 of the Hetch Hetchy funds in building 22 miles of conduit, consisting of 5-foot diameter pipe—capacity for delivery under Hetch Hetchy conditions of 43 million gallons daily—from Irvington, through Pulgas Tunnel, to Crystal Springs Reservoir. As consideration for the lease of this conduit by the Water Company the City receives an annual

rental of $250,000. Under the same agreement, the City holds an option good until December 31, 1933, to purchase the Water Company's system and the lands enumerated above for $38,000,000.

THE HETCH HETCHY PROJECT IN A NUTSHELL

The Hetch Hetchy Project is one to provide an adequate municipal water supply, evolved by the City and County of San Francisco, after a thorough and comprehensive study of all possible sources. The general plan contemplates the collection and storage of waters of the Tuolumne River and its tributaries near their sources in the Sierra Nevada Mountains, and the transmission of those waters across the San Joaquin Valley and through the Coast Range Mountains for delivery to the City of San Francisco and its environs; due advantage being taken of appropriate drops in the conduit routes for the generation of the maximum quantity of hydro-electric power which can be economically developed.

HISTORY

The project had its beginning back in 1901, when the Mayor of the City filed water appropriations on the Tuolumne River and its tributaries, Cherry River and Eleanor Creek. These appropriations were kept alive by preliminary development work until a permit was obtained from the Federal Government for the acquisition of storage reservoir sites situated on public lands within the limits of the Yosemite National Park (not Yosemite Valley). This was granted by Secretary of the Interior Garfield in 1908 relative to lands and waters tributary to the Tuolumne River in the northern part of the Park and twenty miles distant from the Yosemite Valley proper, which latter is drained by the Merced River. Having secured this permit, San Francisco proceeded to acquire, at an expense of $1,915,000, all privately owned lands in the Hetch Hetchy Valley and the rights and holdings of William Ham Hall, John Hays Hammond and others on the Tuolumne and Cherry Rivers and on Eleanor Creek, a tributary of the Cherry. With the accession of the Ballinger administration in the Interior Department, a movement was started by certain coteries of so-called "nature-lovers," and others, to revoke that portion of the Garfield permit relating to the Hetch Hetchy Valley, which was the largest of the proposed reservoir sites. Secretary Ballinger went out of office after having issued an order directing San Francisco to show cause against this revocation. President Taft ordered an investigation and report by a Board of United States Army Engineers, consisting of Colonel John Biddle, Lieutenant-Colonel Harry Taylor and Major Spencer Cosby. This board of engineers examined exhaustively all alternative sources of supply which had been suggested as available for San Francisco's use, including the Stanislaus, Calaveras, Mokelumne, Cosumnes, American, Yuba, Feather, McCloud, Sacramento, Eel, and San Joaquin Rivers, and the local sources of the Spring Valley Water Company. The Army Engineers' report, made to Secretary Fisher, Mr. Ballinger's successor, under date of February 19, 1913, recommended the use of the Hetch Hetchy Valley and the Tuolumne supply as being not only the most available but the cheapest and most economical for the City's use and affording the greatest hydro-electric development possibilities. Previous to the report of this board of engineers, the City had an exhaustive examination of all available sources made by John R. Freeman, an engineer of national repute, associated with the water supplies of Boston and New York. He strongly recommended the Tuolumne source as the best and outlined the scheme of development which, with some necessary modifications, is now being followed.

After taking testimony and examining all reports submitted, Secretary Fisher gave it as his opinion that Congress alone had the power to grant the privileges

sought by the City. After a great deal of argument before Congress, the Hetch Hetchy grant was passed by both Houses and signed by the President on December 19, 1913. This act was framed on the recommendation of Secretary Lane of the Interior Department and Secretary Houston of the Department of Agriculture, and by it Congress (Stats. 1913, p. 242) granted forever to the City rights in 420,000 acres of the public domain.

The water rights have, from their inception, been carefully protected and title to the same is fully vested in San Francisco under the provisions of the Civil Code of California. Antecedent to this, on January 14, 1910, the people of San Francisco, by a vote of 32,886 for and 1,609 against, authorized the issuance of $45,000,000 of bonds for the construction of the project.

Actual work was commenced as soon as the Congressional grant was obtained. Surveys were completed, many miles of wagon road were constructed, a standard gauge railroad 68 miles long was located and built, the floor of Hetch Hetch Valley was cleared of timber, a sawmill was installed and put in operation, diamond drill borings were made at the main damsite and along the line of the tunnel aqueduct, a construction power plant was built, together with a dam at Lake Eleanor, storing nine billion gallons to carry the plant through the dry season, and an aqueduct to supply the plant with water. Twenty-two thousand volt transmission lines connect it with all working points on the tunnel aqueduct, camps and warehouses. Headquarters buildings were constructed, and work has been completed on the Mountain Division, including the O'Shaughnessy Dam at Hetch Hetchy, the Mountain Aqueduct, Priest Dam, power tunnel, pressure pipes, Moccasin Power House, and tower line for transmission of electrical energy to San Francisco as far as Newark.

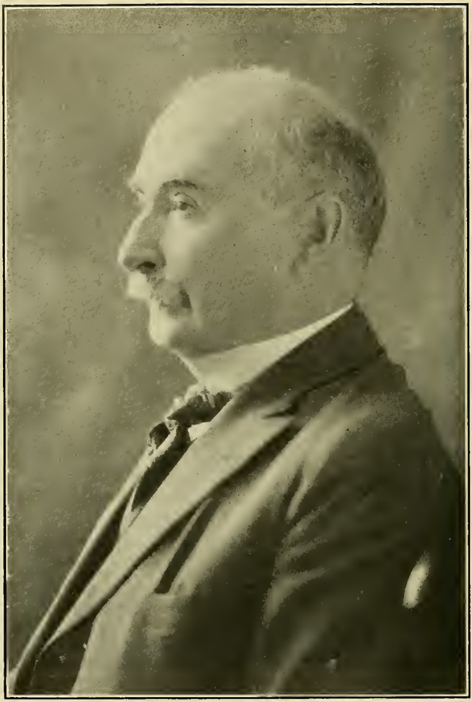
During the period of the war the City carried on work with a force of from 400 to 500 men, with due care always not to interfere with the selective draft or the nation's need for materials and equipment. Progress was necessarily not as rapid as would otherwise have been the case. Sound economic reasoning dictated that the Mountain, or power-generating, division, of the project be completed first, in order that the burden upon San Francisco's taxpayers of paying interest during construction might be reduced by revenue from power at the earliest possible moment. The dominant purpose of the project is, however, water supply, and every effort must be made to complete the water conduits without unnecessary delay in order to remedy the water shortage from which San Francisco has long been suffering.

OUTLINE OF THE PRINCIPAL ENGINEERING FEATURES

The space afforded in this resumé suffices for only a brief description of the principal engineering features of the project. For convenience the work has been divided into ten divisions, known as the Lake Eleanor, Hetch Hetchy, Mountain, Priest, Moccasin, Foothill, San Joaquin, Coast Range, Bay Crossing and Peninsula divisions. Surveys, geological and engineering studies have so far been conducted over the entire work and construction done on all divisions except the San Joaquin and Coast Range.

ORGANIZATION

The Hetch Hetchy development is one of the activities of the Department of Public Works of the City and County of San Francisco. The City Engineer is Chief Engineer of the project, and the Chief Assistant Engineer has direct charge of the work. Two construction engineers, located at Groveland and at Palo Alto, report to the Chief Assistant Engineer. Legal matters are handled by special counsel and rights-of-way by a right-of-way agent.



M. M. O'Shaughnessy, City Engineer

The staff consists of:

General	
M. M. O'Shaughnessy, City Engineer	Chief Engineer
N. A. Eckart,	Chief Assistant Engineer
City Office Engineers	
L. W. Stocker	Assistant Engineer
R. P. McIntosh	Hydraulic Engineer
R. J. Wood	Structural Engineer
P. J. Ost	Electrical Engineer
E. P. Jones	Mechanical Engineer
Construction Engineers	
L. T. McAfee	Construction Engineer, Groveland
C. R. Rankin	Construction Engineer, Palo Alto
L. A. McAtee	Assistant Engineer, Groveland
J. H. Ryan	Assistant Engineer, Groveland
A. J. Wehner	Assistant Engineer, Groveland
L. B. Cheminant	Assistant Engineer, Groveland
A. B. Johns	Assistant Electrical Engineer, Groveland

General Office Staff

Robert M. Searls	Special Counsel
Jos. J. Phillips	Right-of-Way Agent
H. W. Kephart	Purchasing Agent

The following are among the experts who have acted as consultants at different times on the project:

Frank G. Baum	Electrical Engineer
Dr. Wm. F. Durand	Mechanical Engineer
Dr. Jas. C. Branner	Geologist
John D. Galloway	Civil Engineer
Professor Chas. D. Marx	Civil Engineer
Professor Charles Wing	Civil Engineer

PROGRAM ADOPTED

In starting any business enterprise it is of the highest importance that the income which is to support the enterprise should commence as early as possible, so that the interest and other fixed charges on the investment shall not be a dead-weight on the investors any longer than absolutely necessary.

In the case of the Hetch Hetchy Project, it required only the construction of the main storage dam and the upper 20 miles of the aqueduct to reach the 1300-foot power drop at Moccasin Creek. Hence the decision was made to concentrate all energy and financial resources on the works above the Moccasin Creek power plant site for the two-fold purpose of developing and protecting our water rights and producing an income from hydro-electric energy that could be applied to reduce the burden of interest and bond redemptions during the later construction of the aqueduct between Moccasin Creek and San Francisco.

With the greatly advanced prices of labor and materials resulting primarily from the World War, exceeding pre-war prices by 70 per cent, and the wider scope of the project as evolved under the Hetch Hetchy grant, and also on account of the necessity of selling bonds at a substantial discount for several years, the completion of the units mentioned will exhaust the funds realized from the $45,000,000 bond issue of 1910. The completion of the aqueduct will require money to be obtained from further issuance of bonds, but the revenue from power sales and from the Spring Valley Water Company will meet, to a very large extent, the interest on the new bonds; so the wisdom of the course adopted is thus apparent.

Construction Begun

Hetch Hetchy Water Supply Contract No. 1, awarded July 8, 1914, covered the grading of nine miles of 22-foot roadway from Mather to Hetch Hetchy, which hitherto had been accessible only by trail. The road was completed in March, 1915.

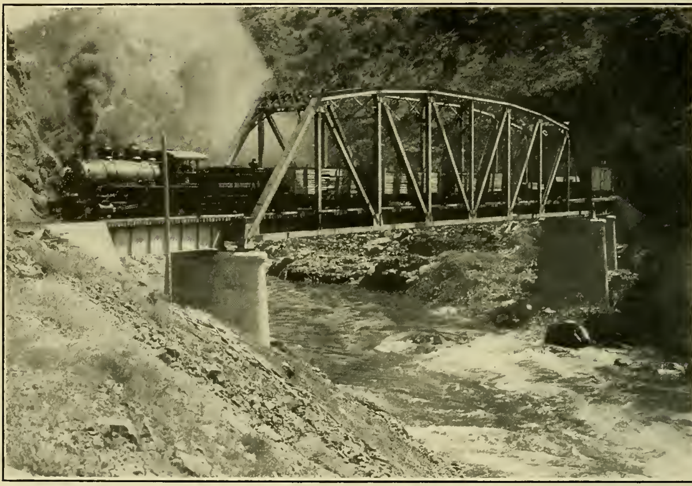
A diversion tunnel 20 feet in diameter, to deflect the main Tuolumne River, was then excavated in the south wall of the Hetch Hetchy gorge around the damsite. Timber clearing was commenced in the reservoir area, and borings were made at the damsite to determine the depth to bedrock in the river bottom.

Up to the present date, 106 public contracts for all features of the work, aggregating $25,000,000, have been awarded by the Board of Public Works after appropriations have been made by the Board of Supervisors, based on open bidding

on plans and specifications prepared by the City Engineer. There has been no breath of scandal or insinuation of any kind relative to any of these contracts or any other phase of the work.

Railroad

To transport equipment and materials to Hetch Hetchy Dam, the aqueduct tunnels and the power plant, a standard gauge railway was built on grades not exceeding 4 per cent and on curves not exceeding 190-foot radius, extending along the entire upper end of the work in the foothill and mountain divisions. The Hetch Hetchy Railroad, 68 miles in length, connects with the Sierra Railway at Hetch Hetchy Junction, 26 miles from the town of Oakdale, and extends to O'Shaughnessy Dam.



Hetch Hetchy Railroad, Tuolumne River Bridge

Starting at Hetch Hetchy Junction, at an elevation of 935 feet, the route leads across rolling country and descends into the Tuolumne River Canyon to 600 feet elevation. It then follows up the river, crossing it on a steel bridge below Jacksonville. At Moccasin Creek a steep climb begins, and continues until elevation 3070 is attained at mile 26, near the headquarters town of Groveland. From this point east the line follows generally the dividing ridge between the Tuolumne and Merced Rivers. Thence the general elevation increases until at mile 62 the summit is reached —Poopenaut Pass—at elevation 5064. Six miles of continuous descent on a 4 per cent grade complete the 68 miles to Damsite, where the elevation is 3870 feet. The last nine miles of the railroad was built on the roadbed previously graded and used as roadway.

The railroad serves the working points of the 30 miles of main aqueduct east of the Sierra Railway, the Moccasin power development, and the City's sawmill,

some directly, others through short spur tracks, tramways, or motor truck hauls. Haulage from the railroad is generally in the downhill direction.

Snowplow at Mather Station, Hetch Hetchy Railroad

Early Intake from Hetch Hetchy Railroad

The railroad was commenced in 1916—with over 1,000,000 cubic yards excavation, and completed in October, 1917. It was operated from July, 1918, to February, 1925, as a common carrier. Freight rates were on a basis of 12½ cents per ton mile for carload lots for all freight except lumber and livestock, on which commodity rates were established. The basis of passenger fares was 7½ cents per mile.

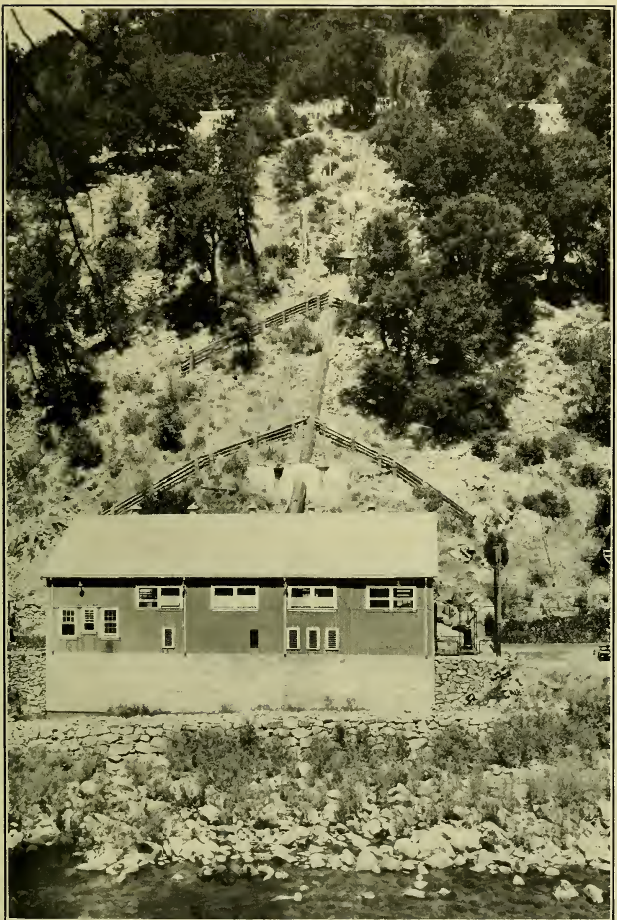
The cost of construction of the railroad was about $3,000,000. The early use of the road enabled the City to complete the O'Shaughnessy Dam in April, 1923, in three and one-half years, and thereby gave San Francisco priority to the flood waters of the Tuolumne River.

The completion of the Don Pedro Reservoir by the Turlock and Modesto Irrigation Districts necessitated the relocation of the Hetch Hetchy Railroad at the Six Bit Gulch crossing, the old trestle at this point being four feet below the flow line of the reservoir. The trestle was replaced by a nine-span plate girder bridge, 585 feet long, 15 feet higher in elevation than the old trestle. The reconstruction of this bridge and the relocation of adjacent stretches of track were made on request of, and were paid for, by the two irrigation districts.

Sawmills

Sawmill machinery was purchased in August, 1915, and a sawmill erected at Canyon Ranch, five miles from Hetch Hetchy. After six million board feet of lumber had been sawed at this location, the supply was exhausted and the sawmill moved to Mather. At Mather it continued to operate until the winter of 1923-1924, when, having served the needs of the present construction, its operation was dis-

City Sawmill at Mather Station, Hetch Hetchy Railroad



Construction Power House at Early Intake. General view showing forebay flume, penstock and building.

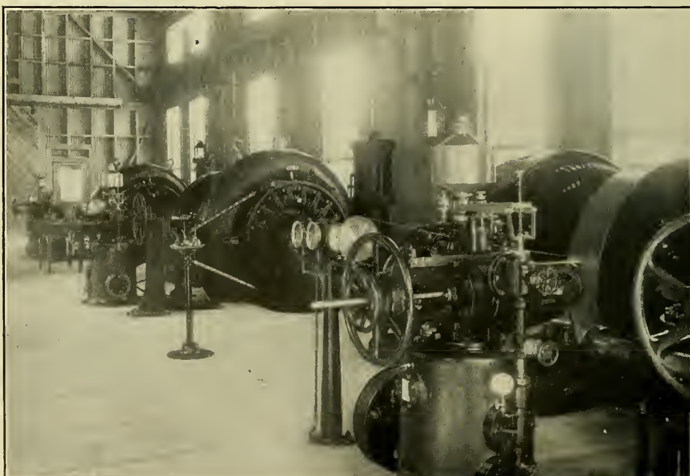
continued. Lumber from the mill was used for concrete forms, camp buildings, flumes, tunnel timbering, and miscellaneous structures. High-grade lumber, such as sugar pine and white pine, not required in the City's work, was traded to privately operated mills to advantage for cheaper woods. A total of 21 million feet B. M. was cut.

LOWER CHERRY POWER SYSTEM

To operate construction equipment in the mountains, a 3000 K. V. A. power plant was installed near the mouth of the Cherry River. The construction was commenced in the summer of 1916, and completed, ready for operation, in June, 1918.

Water for this installation is diverted from Cherry Creek into a conduit of 200 second feet capacity, 3.3 miles long, consisting of 1.2 miles of tunnels, 1.1 miles of flumes, and 1 mile of concrete lined canals. The power house contains three turbines, operating under a maximum head of 345 feet, fed by a 42-inch pipe line 530 feet long, each direct connected to a 2300 volt, 1000 K V. A. generator. Power is transmitted at 22,000 volts 11 miles east to O'Shaughnessy Dam and 22 miles west to Moccasin Creek, supplying intermediate substations along the line. Since the completion of Moccasin power plant the Cherry aqueduct has been extended one-half mile to Early Intake Diversion Dam so that the Lake Eleanor water can be passed through the main aqueduct to Moccasin.

This system has furnished power for all the Hetch Hetchy Water Supply activities as required, except the main sawmill drive; and surplus power has been sold to the Pacific Gas & Electric Company through a connection at Priest. Two interruptions of power operation from February 25, 1922, to April 21, 1922, and from February 25, 1923, to March 14, 1923, resulted from landslides carrying away portions of the open concrete lined canal, and one from November 28, 1921, to December 18, 1921, from a shortage of water. Those breaks caused serious loss in



Construction Power House at Early Intake. Interior showing three Pelton Francis turbines direct-connected to 1000 K.V.A. generators

the continuous operation of the work until a dependable outside standby service was connected up. During such interruptions power was drawn from the Pacific Gas & Electric Company system to supply the westerly end of the work.

LAKE ELEANOR

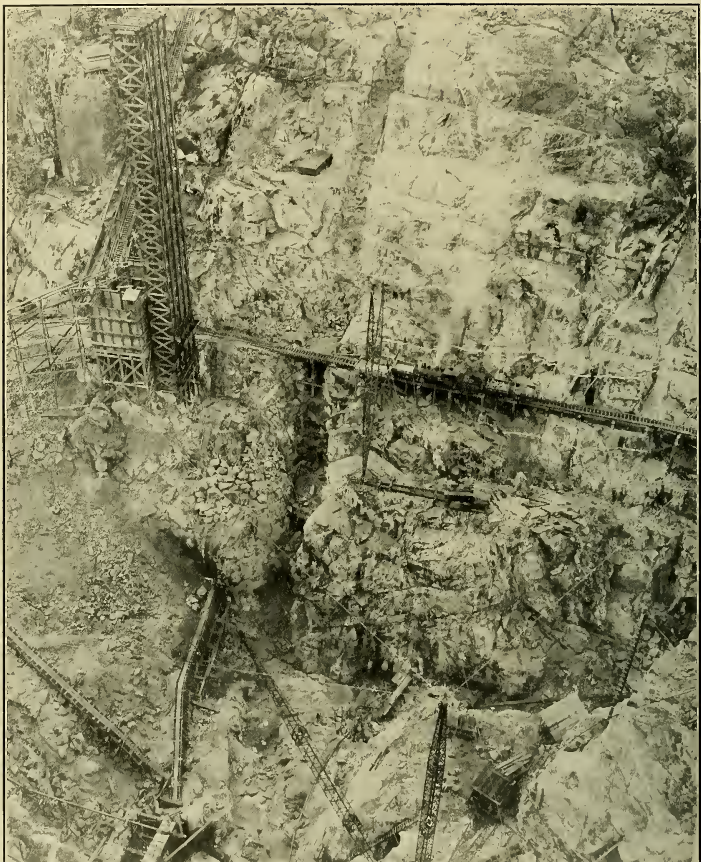
To permit the operation of the power plant during the low water season, it was necessary to develop a certain amount of storage at Lake Eleanor. The construction of Lake Eleanor Dam was commenced in August, 1917. It was put in service in June, 1918. The dam is 1260 feet long and 70 feet in maximum height. It contains 11,640 cubic yards of concrete, heavily reinforced. It is of the buttressed arch type, with several original features developed by the City Engineer's studies. There are 20 arches, each with a span of 40 feet. These arches are on an incline of 50 degrees to the horizontal and are supported by buttresses. The dam is curved in plan. One interesting feature to the engineer is that the cross-section of the arches follows a circular arc on a horizontal plane, and an elliptical arc on a

Lake Eleanor multiple arch dam which impounds 27,800 acre feet

normal plane, which is the reverse of the usual construction heretofore used in this type of dam. Over the entire length of the dam is a reinforced concrete roadway, 12 feet wide.

The stored water is withdrawn through two 24-inch sluice gates, placed on the face of the dam.

The dam was completed late in 1918, but had already been put to use for storage of water to operate the Lower Cherry power plant. The entire cost of the



O'Shaughnessy Dam. Deepest point of excavation for foundation, 118 feet below bed of Tuolumne River. Outline of dam shown by white lines on the rock

structure, including a 12-mile wagon road from Hetch Hetchy costing $28,000, was about $320,000.

The flow line of the reservoir created by the dam is at elevation 4660 feet, and its capacity is about 27,800 acre-feet, or nine billion gallons. This quantity is only a small part of the annual runoff from the Lake Eleanor watershed, and the reservoir is filled each year early in the flood season.

O'SHAUGHNESSY DAM

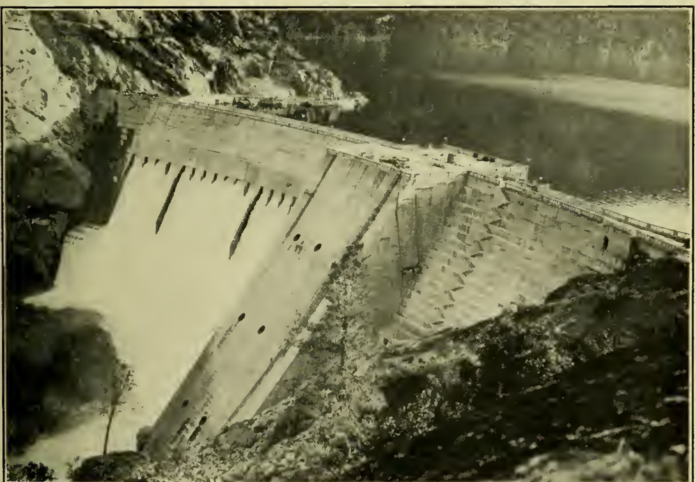
The contract for the construction of the first installment of the O'Shaughnessy Dam across the Tuolumne River at the outlet of Hetch Hetchy Valley, was awarded after open bidding August 1, 1919, to the Utah Construction Company.

The dam is of the arched gravity type—700-foot radius—built of cyclopean concrete (concrete in which are imbedded large blocks of stone ranging in size from about one cubic foot to five or six cubic yards).

When the water supply or electric power requirements demand, the dam will be raised to its ultimate height and thickness. So great is the present-day demand for hydro-electric power, and so constantly is it increasing, that the completion of the last addition will probably be governed by power needs rather than consideration of the water supply.

All foundation work below stream level for the ultimate structure has been completed with the present construction.

When it becomes necessary to add to the reservoir capacity developed by the initial dam, the dam will be brought up to its full ultimate size by adding a thickness of 80 feet on the downstream face of the initial dam and building up 85 feet higher. This will make available 80 feet additional depth of reservoir, and will make the



O'Shaughnessy Dam. The heavy valve section in the center is full thickness for the dam when built to its ultimate height 85 feet above the present crest

lake 300 feet deep at the dam. The total height of the dam above the foundations will then be 430 feet. This is higher than any dam now in existence.

The initial dam has a height above the original stream bed of 226.5 feet, and a maximum height above foundations of 344.5 feet, and contains 398,516 cubic yards of concrete. The length on the crest is 605 feet and the thickness on the crest is 15 feet. The thickness of foundation is 298 feet. The present wasteway consists of 18 spillways of the siphon type, discharging over the downstream face of the dam.

The floor of Hetch Hetchy Valley has been cleared of timber, in order to protect the impounded waters from contamination due to the decay of submerged timber.

Valves for Outlet System

Valves to control the discharge of water for irrigation and domestic use through the dam as required, have been installed at various levels. Openings, designated as supply pipes, supply wells, and discharge conduits, have been cast in the concrete as the structure was built.

The valves consist of the following:

Six 5-foot balanced needle valves;
Six 3-foot balanced needle valves;
Six 47-inch by 90-inch slide gates;
Six 33-inch by 42-inch slide gates.

The valves and their appurtenances comprise over two million pounds of metal of high-grade design, and cost nearly $700,000.

On each opening through the dam there are two controls. The water is admitted through the hydraulically operated slide gate to the supply well and from there the required flow is regulated and discharged by the balanced needle valves. These valves are of the latest type of hydraulically balanced valve which permit manual control of a plunger weighing five tons, under a high head of water. The water discharges in an annular ring surrounding the plunger.

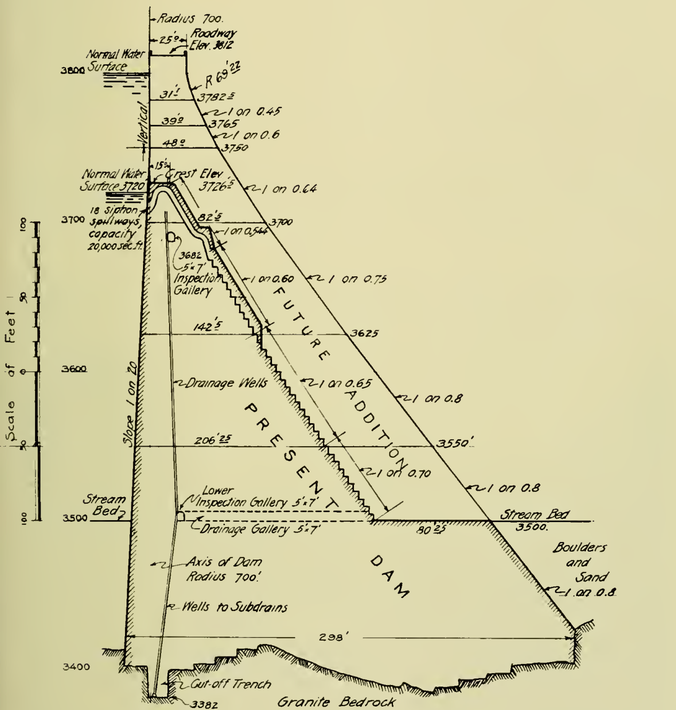
The six 5-foot balanced valves and the six 47-inch by 90-inch slide gates are installed in the main portion of the dam, being set in the concrete as the structure advanced. Three of the 3-foot balanced valves are installed on the lower side of the dam at elevation 3625, in a special valve house, and have three 33-inch by 42-inch gates installed in the dam in connection with them. Three 36-inch needle valves and three 33-inch by 42-inch slide gates are installed in the concrete plug in the diversion tunnel and permit draining the reservoir to its lowest levels. All sluice gates can be made accessible for repairs by closing the inlet tunnels by means of steel shutters in concrete slots.

Spillway

The temporary spillway of the initial dam consists of 18 siphons, each 4 feet by 10 feet at the throat, and placed in three series at slightly different levels. The siphon openings are heavily reinforced with steel. Each siphon has a capacity of approximately 1,000 cubic feet per second. The spillway has operated successfully since May 25, 1923, when the reservoir first reached its flood limit. The water discharging from the siphons down the steps on the back of the dam forms a waterfall of imposing appearance.

It is the plan, on the final completion of the dam to full height, to bypass the floods through canals and tunnels at either end past the abutments of the dam so as to clear the structure altogether, and plug the existing siphons with concrete.

The top of the dam is finished with a 17-foot roadway, on the sides of which are placed precast concrete railings, which add an artistic finish to the structure. A concrete girder bridge connecting the dam to the Eleanor road harmonizes with the main structure. The east abutment of the bridge is on roller bearings to provide adjustment to meet temperature changes and consequent movement in the arched dam.



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA.

O'SHAUGHNESSY DAM
AT
HETCH HETCHY VALLEY

CROSS SECTIONS SHOWING PRESENT AND FUTURE DAMS.

DEPARTMENT OF PUBLIC WORKS.

APPROVED M.M. O'Shaughnessy CITY ENGINEER

BY L.B.C. TRACED L.B.C. CHECKED R.P.MC.

SCALE As shown DATE June 12, 1925.

A 287.

In order that the foundation of the dam might be constructed in the dry, a rock-filled timber crib dam was built above the location of the main dam, and a concrete backwater dam 800 feet downstream, thus passing the water around the damsite through the diversion tunnel which had been enlarged to 23 feet by 25 feet. Excavation down to 65 feet below streambed was accomplished with steam shovels and dump cars; below that level derricks and skips were used.

At elevation 3439 at the downstream toe, bedrock was encountered and a concrete retaining wall, 31 feet in height, was built, sealing off all seepage into the lowest portion of the foundation. At the upstream toe, on reaching an elevation of 3435 feet, a cofferdam was sunk to bedrock, elevation 3399, and a concrete retaining wall was poured, cutting off practically all seepage into the excavation.

After removing all material overlying the granite bedrock, this was roughened to receive the concrete. A sand-blast was used in places to roughen the glazed and polished surfaces of the pot holes in the water-worn rock formed by pre-historic cascades from ancient glaciers. This provided a clean, rough surface for bonding the concrete.

Concrete was placed with chutes from a wooden, four-compartment hoisting tower, 375 feet high, built on the south side of the canyon. After the forms were removed, a coating of gunite was applied to the upstream face.

During the cold weather period each year from December to March, a heating

Hetch Hetchy Reservoir. View east showing central three miles of reservoir. Kolana Rock on right, rises 1800 feet above floor of valley

plant, consisting of a large steam boiler and circulating pipes, was installed to prevent the concrete from freezing.

Large stone, or plum rock, was placed in the cyclopean concrete to an amount not exceeding 8 per cent of the mass.

Rock for concrete was crushed in a plant located on the valley floor upstream from the damsite. Sand was excavated about three miles upstream from the damsite and hauled to the work on a 3-foot gauge construction railroad, with ten locomotives, and there screened, stored and reconveyed to the mixers. Plum rock was taken from the talus slopes on the north side of the valley and hauled one mile to the dam on flat cars. Cement in bulk was unloaded from cars on the Hetch Retchy Railroad into a bin above the dam, and conveyed to the mixers by gravity.

Concrete placing began in September, 1921, and finished in February, 1922; 398,516 cubic yards being placed.

The dam was completed in May, 1923. The cost of construction by the Utah Construction Company was $6,121,000. On May 24 the reservoir was completely filled and the siphon spillway began discharging the flood waters.

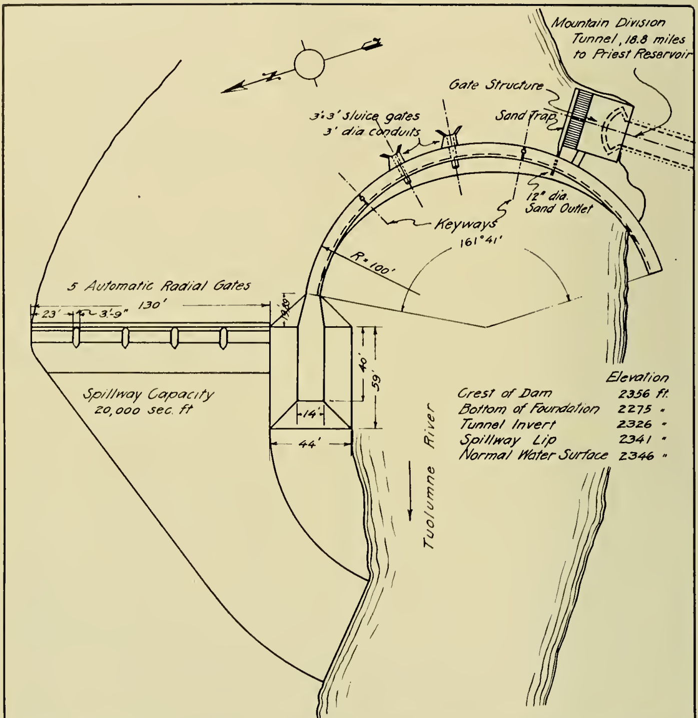
A turbine generator and storage battery were installed in the bypass tunnel to supply power to meet local requirements at O'Shaughnessy Dam when the existing transmission line from Early Intake to the dam is removed.

EARLY INTAKE DIVERSION WORKS

The water released from Hetch Hetchy reservoir flows, for the present, 12 miles down the Tuolumne River to Early Intake Diversion Dam. Eventually, it will flow through a 12-mile tunnel and a power house developing 60,000 horsepower and be discharged above the diversion dam. The water from Lake Eleanor, which now flows down Eleanor Creek, Cherry River, and the Lower Cherry aqueduct about 10 miles to the diversion dam, eventually will be carried in an aqueduct about 11 miles long to a power house in the Tuolumne River Canyon about one mile above Early Intake, where 40,000 horsepower will be generated. The water released from the plant will flow down the river channel with the water from Hetch Hetchy and be diverted into the tunnel aqueduct which begins at Early Intake.

The diversion dam consists of a thin concrete arch 262 feet long and a concrete spillway 130 feet long. On the left bank is the aqueduct intake tower with gates regulating the flow of water for San Francisco's use. Water in excess of that diverted to San Francisco and necessary to supply the Turlock and Modesto irrigation districts will pass over the spillway to flow down the Tuolumne River about 40 miles to Don Pedro Reservoir.

The diversion dam has an upstream radius of 100 feet. Thickness at crest at elevation 2356 is 6 feet, at base 16 feet. Height above river-bed is 55 feet and the base extends 26 feet down to solid granite. On the south, the arch abuts the granite canyon wall; on the north is a concrete block containing 3611 cubic yards. From this block the spillway extends northerly, divided by piers into five sections, each 23 feet long, in which automatic radial gates have been installed, whose function is to maintain the water surface at elevation 2346, or 5 feet above the lip of the spillway. Tunnel invert at inlet is at elevation 2326 feet. A siphon arrangement automatically lowers these gates to pass excess floods and allows them to rise after the flood has subsided. In constructing the arch section of the dam, two vertical openings with keyways 18 inches wide, were left at the points of approximate zero bending



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA

EARLY INTAKE DIVERSION DAM

GENERAL PLAN

100 50 0 100

Scale of Feet

DEPARTMENT OF PUBLIC WORKS. APPROVED M.M. O'Shaughnessy CITY ENGINEER

BY L.B.C. TRACED L.B.C. CHECKED R.P.M.F.

SCALE As shown DATE June 4, 1925

A 280.

moment until the dam had taken final set. Then in the extreme cold weather, when the dam had received final set, these keyways were filled with concrete.

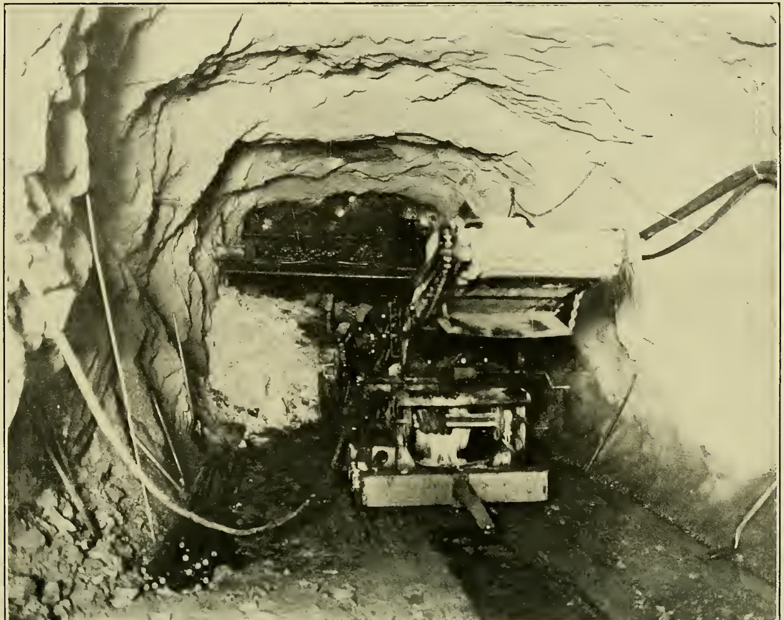
The gate tower at the intake is equipped with fixed grillage outside, to catch heavy refuse; and wire mesh, manually operated, traveling screens inside, to catch

Early Intake Diversion Dam. View up Tuolumne River. Flume on left discharges water from Lake Eleanor and Cherry River. Gatehouse on right is the inlet to the 18.8-mile tunnel to Priest Reservoir. Spillway on left, with automatic gates, bypasses flood waters

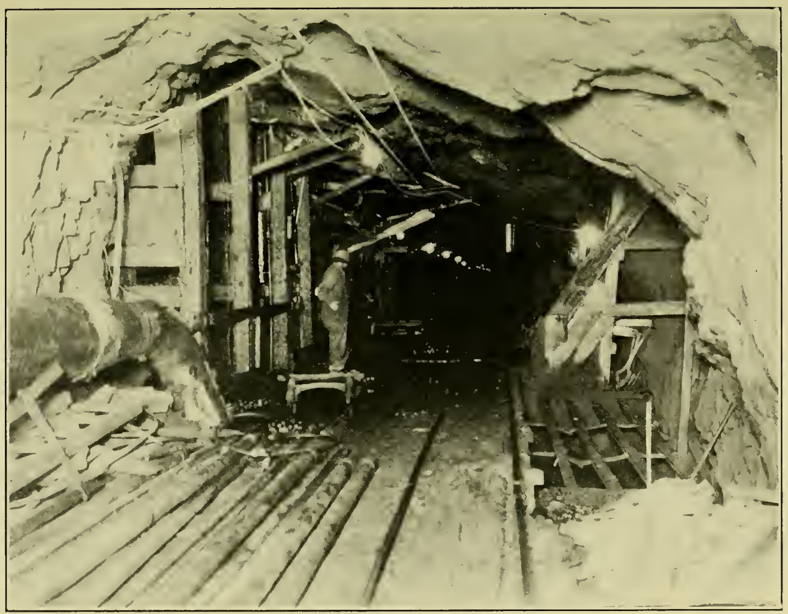
leaves and light refuse. Sand chambers in front of the screens discharge through the dam. There are 9 sluice gates, 4 feet by 5 feet, 5 in the lower tier and 4 in the upper. These are set in a thin reinforced concrete arch of 16 feet radius abutting on the rock wall of the canyon. A concrete house covers the operating wheels, screen mechanism, etc., the whole structure being protected from falling rocks from the adjacent mountainside by a reinforced concrete guard wall on the uphill side of the intake. The dam, spillway and gate structure contain 16,564 cubic yards of concrete.

Mountain Division Tunnels

The Mountain Division Tunnels extend 18.8 miles from here to Priest Reservoir. The first half mile of tunnel skirting under the canyon wall is 14 feet 3 inches high by 13 feet 4 inches wide, with top arched to 6 feet 8 inches radius, bottom to 20 feet 5 inches radius, has 166.5 square feet neat excavation, and is unlined, except for a few short stretches. The next seven miles, also unlined, is excavated to 13 feet 6 inches high by 13 feet 4 inches wide, with top arched to 15 feet radius and bottom to 20 feet 5 inches, with neat area 167.8 square feet. This section is interrupted near mile No. 5 by 225½ feet of 9 feet 6-inch diameter riveted steel pipe, which carries the flow across the south fork of Tuolumne River. The pipe is a continuous beam of four unequal spans, the longest being 74 feet across the main channel, and is supported on concrete piers whose reinforcmeent extends into holes drilled in the bedrock. An expansion joint is introduced at the point of contraflexure



Mountain Division Tunnel. Heading showing air drills on bars, muck pile and electrically operated mucking machine

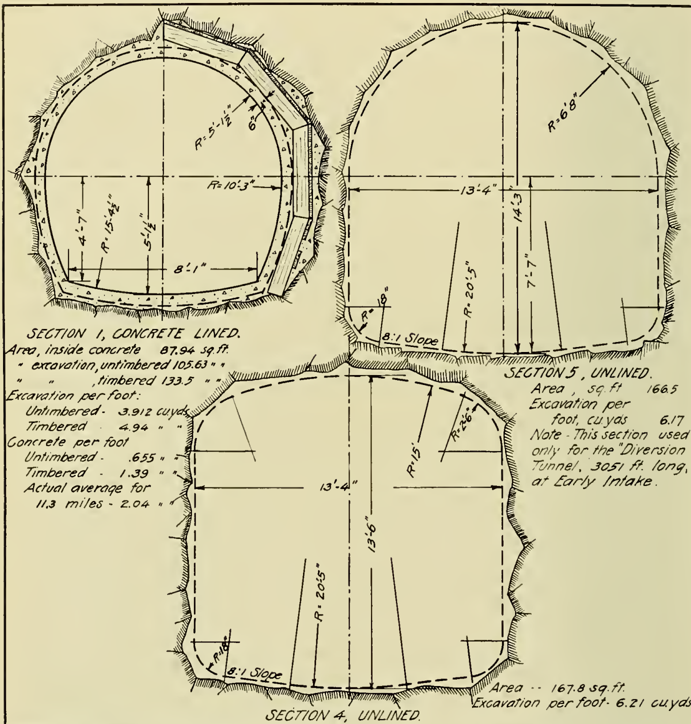


Tunnel station at Big Creek Shaft. Rock pocket at right, ventilating air pipes on left, three compartment shaft on left

nearest the upstream anchor. The pipe is covered with heavy timber to prevent damage from rocks falling from the cliffs above.

The remainder of the tunnel, about 11.3 miles, is lined throughout with 1:2¼:4½ concrete with minimum thickness of 6 inches.

This tunnel is of horseshoe shape 10 feet 3 inches high by 10 feet 3 inches wide, of 87.94 square feet net area inside of lining. The rock encountered consisted of



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA

STANDARD TUNNEL SECTIONS

USED IN

HETCH HETCHY AQUEDUCT

DEPARTMENT OF PUBLIC WORKS. APPROVED M. M. O'Shaughnessy CITY ENGINEER

BY LBC TRACED LBC CHECKED RPMcG

SCALE ¼ inch = 1 foot DATE June 9, 1925

A 282

Aqueduct tunnel, showing concrete lining of sides and arch with concrete forms in place

diorite, quartzite, slate and amphibolite schist. The tunnel with a grade of 0.00155, or about 8 feet per mile, has a capacity of 620 second feet.

Excavation was carried on from 12 working faces: one at each end portal, one on each side of the stream crossing, four from two adits and four from two shafts. The first heading was begun at the south fork Tuolumne River crossing, July 7, 1917, proceeding easterly. Big Creek shaft was opened in February, 1918, and tunneling begun from 575 feet below the collar in August, 1919. The shaft was 646 feet deep. Second Garrote shaft, 786 feet deep, was begun in November, 1918, but encountered excessive amounts of water as high as 2,000 gallons per minute, which delayed its completion until December, 1922. The last connection in driving the 18.8-mile tunnel was made between Big Creek shaft and Second Garrote shaft on November 26, 1923.

Muck car trains in the tunnels were hauled by electric storage battery locomotives. Electric mucking machines were used at all headings except while working out from Big Creek and Garrote shafts, which were too small to allow the convenient passage of the electric machines. At these headings smaller air operated mucking machines were used. A spare machine was maintained at each camp to insure continuity of service. Electrically driven air compressors and blowers were used at all the camps. At Second Garrote shaft a steam driven air compressor was maintained for standby service to insure against failure of electric power supply.

The rate of progress varied according to the formation, from 300 to over 700 feet per month. The best record for one month was 776 feet, made from the Priest (west) portal of the tunnel. This established a new United States speed record for hard rock tunnel driving.

Tunnel lining was begun with one plant on March 20, 1923; after April, 1924, two plants were working and completed the lining in May, 1925. The total distance lined is 60,630 feet.

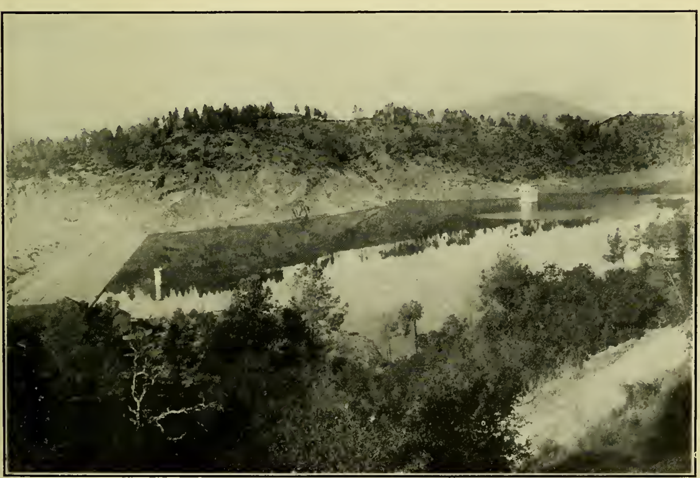
PRIEST REGULATING RESERVOIR

At the west tunnel portal at elevation 2170 the water enters Priest Reservoir, created to provide forebay capacity for the fluctuating demand of the Moccasin power plant. The reservoir was made by constructing an earth fill dam with concrete core wall across Rattlesnake Creek. This forebay reservoir contains 2350 acre feet, or over two days' flow of the tunnel. Priest Dam is 1160 feet long and 145 feet high. Crest width at elevation 2245 is 20 feet. The dam is 660 feet thick at its base and contains 717,283 cubic yards of earth and rock fill and 17,043 cubic yards of concrete in the core wall, which extends 15 feet deep into bedrock. To provide a certain degree of flexibility the core wall is divided into panels 50 feet long by 16 feet high, water stops of 16 gage copper being placed in the joints between panels. Some 27 tons of copper are used in the structure for this purpose.

The embankment consists of rock spoil from the tunnels placed in the up and downstream toes, earth fill placed by hydraulic methods and earth fill placed by dump cars from steam shovel and sluiced into place by water jets. The slope of the upstream face is 2½ to 1; downstream face is 2 to 1 slope except the rock toe, which is 1¾ to 1. The upstream face is riprapped to prevent erosion from wave action.

A concrete lined spillway 40 feet wide, with lip at elevation 2240, protects against overtopping. An outlet and drainage tunnel 6 feet in clear diameter, with inlet at elevation 2120 feet, was driven through the solid rock of the east abutment and lined with 12 inches of concrete. Valves in the tunnel are reached by a vertical,

Priest Dam. View down Rattlesnake Creek. Track in left center marks outlet of 18.8-mile tunnel. Power Tunnel begins near sheds in right center

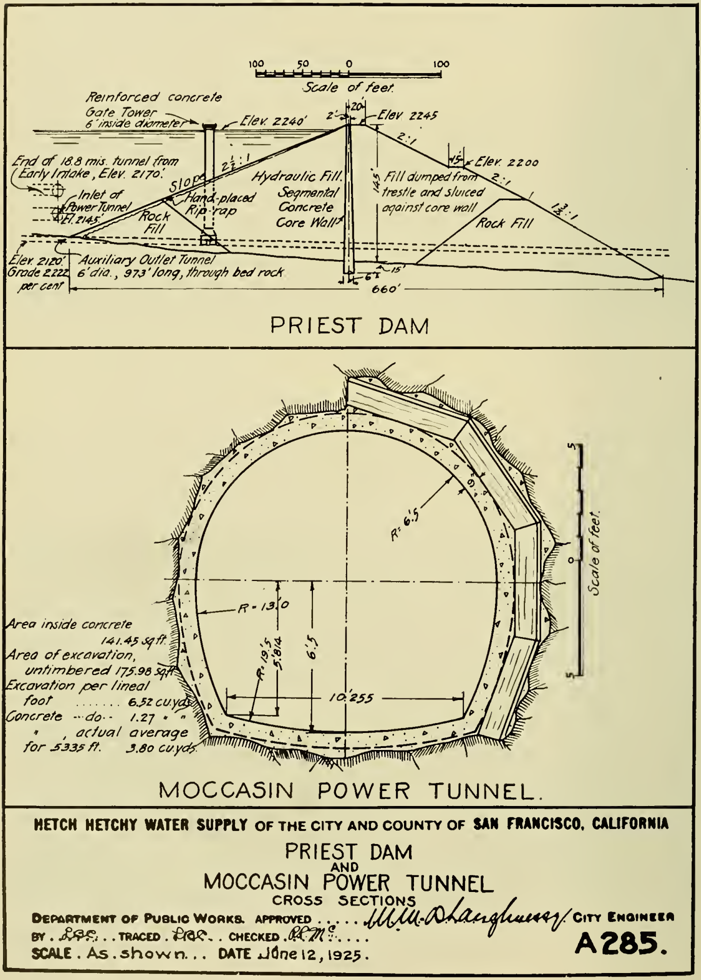


Priest Regulating Reservoir. Dam at left. Gatehouse in upper right is at entrance to Power Tunnel which is 95 feet below high water. Mountain Division Tunnel discharges near house in right center, 70 feet below high water

circular concrete tower of 6 feet inside diameter. The tunnel and tower contain 1954 cubic yards of concrete. The dam was begun in January, 1922, and completed in August, 1923.

Moccasin Power Tunnel

Water discharging from the reservoir to the power house enters Moccasin Power Tunnel at elevation 2145 through a concrete control tower, oval in plan,



65 feet by 36 feet, inclusive of semi-circular, precast screen rack projecting into the reservoir. The structure contains 2765 yards of 1:2:4 concrete. Six electrically operated sluice gates, each 6 feet by 8 feet, provide for cutting off water to the tunnel. Manual operation is also possible and steel shutters are provided for isolating any set of gates for repairs, if necessary. Fixed screens with manually operated cleaner prevent fine trash from entering the tunnel.

The tunnel begins as the frustum of an oblique cone tapering from about 19 feet width and height to 13 feet standard section in a distance of 30 feet. The tunnel section is 141.47 square feet with grade of 6 feet per 1000, making its capacity 1240 second feet without excessive loss of head. The minimum thickness of concrete inside of timbering is 9 inches; the concrete averages 3.8 cubic yards per lineal foot. The tunnel extends 5370 feet to the inside wall of a surge shaft 40 feet in diameter, which serves as a manifold for the three penstock pipes, which are imbedded in concrete in tunnels 535 feet long, leading from the opposite side toward the power house.

Surge Shaft

The surge shaft is designed to handle surges of from 35 to 40 feet. The floor is at tunnel grade, elevation 2112, and the height to the rim is 160 feet. It projects 48 feet above the surface of the ground. The walls of this portion range in thickness from 24 inches to 10 inches and contain heavy reinforcement, the maximum of which is two rings of 1½-inch square bars staggered at 7-inch centers. Accumulation of external water pressure below the ground surface which might result from surface runoff, is prevented by a system of porous cement drain tile. The shaft contains 2185 cubic yards of 1:2:4 concrete.

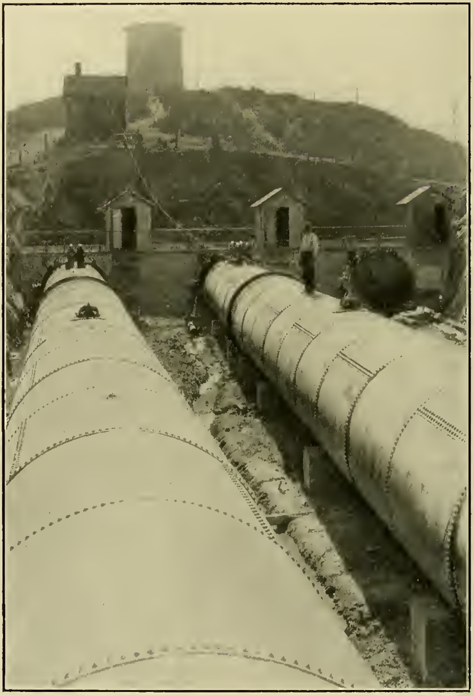
Penstock Pipes

The three penstock pipes, the horizontal length of which is 5349 feet, begin at the wall of the surge shaft, each as the frustum of an oblique cone with large diameter 12 feet 4 inches. The smaller end connects to the 104-inch diameter riveted steel pipe. About 50 feet westerly from the tunnel portal in each line a 104-inch diameter butterfly valve has been installed. The most southerly pipe is dead-ended at the valve pending future extension when two more generators shall have been installed in the power house. The butterfly valves are motor operated and arranged for closing by remote control from the power house. As a matter of precaution the opening control is at the valve only. Two sets of four 8-inch air valves are installed in each line immediately below the valves.

The thickness of pipe plate at the surge shaft is ⅜-inch. At elevation 2070 the diameter reduces to 98 inches and the double riveted lap joints change to triple riveted butt. At a slope distance of 2111 feet the pipes branch each into two 66-inch diameter pipes of hammer forge welded steel with "bumped" joints of enlarged section, reducing obstruction to stream flow of rivet heads. The welded pipes whose slope length is 3469 feet, range in diameter from 66 to 54 inches and in thickness from 7/16-inch to 1 5/16-inch. Immediately before entering the power house the four 54-inch diameter pipes branch each into two 36-inch diameter pipes in which are installed in an arcade of the power house hydraulically operated 36-inch gate valves.

The total weight of pipe is 12,487,709 pounds, the heaviest section of pipe weighing approximately 26,000 pounds. The 30-foot lengths are supported on some 400 concrete piers, or saddles, built in advance of the pipe-laying. At angles, of which there are 20, either horizontal, vertical or combined, the pipes are held securely by concrete anchors, the largest of which contains 839 cubic yards of concrete and 7.64 tons of reinforcing steel. Expansion joints are provided between anchors. At the 98-inch

by 66-inch "Y" branch is a special sliding anchor in which the upper portion, inclosing the pipes, can slide on cast iron plates imbedded in the fixed concrete of the lower portion.

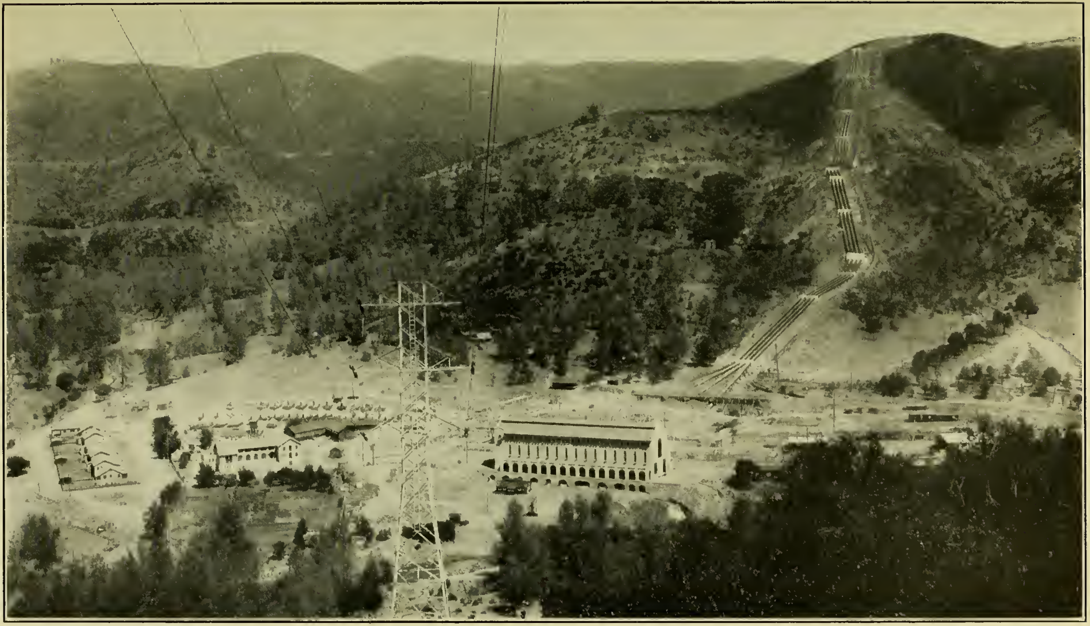


Moccasin Power Plant Penstocks at west end of Power Tunnel. In upper center is the surge shaft where the tunnel divides and pipes begin

MOCCASIN POWER PLANT

This power plant, the largest of the Hetch Hetchy system, uses the full flow of the aqueduct, 620 second feet, dropping from 2240 feet, the elevation of high water in Priest Reservoir, to 924 feet, the elevation of the water wheel nozzles.

The power house, as at present built for four units, is 225 feet long, 98 feet wide and 67 feet high. It is a steel frame building, with massive concrete foundations and with reinforced concrete walls. The architecture is of the California-Spanish style, which is particularly suited to the site. This building houses the generators and low voltage switching apparatus, but the step-up transformers, high tension switches and high tension busses are installed in the rear, out-of-doors, at the easterly side of the building. The busses are carried on a structural steel frame. The 11,000



General view of Moccasin Power Plant showing penstock pipes from Power Tunnel, Power House, beginning of transmission line to San Francisco, operators' quarters, clubhouse and construction camp

volt, 3-phase, 60-cycle current generated, is stepped up to 115,000 volts for transmission to San Francisco. All apparatus, however, is designed for operation at 154,000 volts.

The water wheels were manufactured by the Pelton Water Wheel Company of San Francisco. These are of the double over-hung impulse type and operate at 257 r.p.m. Each has a rated output of 12,500 h.p., or 25,000 h.p. for the unit. The rotating part of each unit weighs 118 tons and can be handled by the 135-ton crane installed in the power house. The static pressure head at the power house is 1316 feet. The water wheel rating is, however, based on an effective head of 1250 feet. The maximum jet diameter is 11 inches. An auxiliary relief needle nozzle is set directly beneath the main nozzle and connected therewith in such manner that it may be operated as a synchronous bypass, or may be set to close automatically to save water.

The generators and exciters were furnished by the General Electric Company. The rating of the generators is 20,000 K.V.A. These generators deliver 11,000 volts directly to the transformers, the arrangement of the power house being such that so far as practicable the generators and the transformers operate together as a unit, provision being made for but one 11,000-volt bus, which can be used to connect any generator to any bank of transformers in an emergency. From this 11,000-volt bus all auxiliary power is taken for use in the operation of the station, and for two 22,000-volt circuits for construction work along the aqueduct line.

The transformers, switchboards and switches were supplied by the Westinghouse Electric and Manufacturing Company. The transformers are single phase, 6667 K.V.A. capacity, with taps which permit of their being operated at either 11,000 to 115,000 volts, or 11,000 to 154,000 volts. They are set out-of-doors in banks of three; complete piping connections are provided for circulating water and for oil filling and filtering. Tracks and transfer cars permit of any transformer being moved into the power house under the crane for repairs.

From the switching station behind the power house, two 154,000-volt circuits will be carried to San Francisco on one double circuit steel tower line. The electric transmission line at the present time has been built as far as Newark on San Francisco Bay, a distance of 98½ miles from the power house; 506 towers are employed in this distance—an average spacing of 1,000 feet. They are placed on the northerly boundary of a 110-foot right-of-way strip, to be supplemented in the future with a similar line on the southerly side. The distance between lines is 24 feet at the top arm, 28 feet at the middle arm, and 24 feet at the bottom arm. The vertical spacing between conductors is 15 feet. The lowest cross-arm is 62 feet above the ground. The conductors from the power house to a point within a few miles of the bay are 397,500 c.m. steel reinforced aluminum conductors. From the point where bay fog is encountered, hemp cored copper conductors are used. These have a circular mil capacity of 345,000, with an external diameter of ¾-inch. At suspension points, 10 units of Westinghouse No. 601 insulators are used, while at dead-end and other points of stress, 12 Westinghouse No. 631 insulators are employed.

Operation of the present two circuits in parallel, as will normally be the case, will permit of transmitting the power generated at the Moccasin plant with a line loss of approximately 8 per cent, and when one line must be taken out of commission temporarily, the remaining circuit will still have capacity to transmit the output of the plant to San Francisco.

Red Mountain Bar Siphon. View showing 9 ft. 6 in. diameter steel pipe incased in concrete, in foreground. Stream diverted and coffer dam constructed preparatory to laying pipe in the east half of channel

FOOTHILL DIVISION

The plan for the aqueduct to San Francisco calls for 17 miles of tunnel in the Sierra foothills below Moccasin Creek, the tunnel being divided into two sections at the Tuolumne River by the Don Pedro Reservoir at Red Mountain Bar. The reservoir is crossed by an inverted steel pipe siphon cased in concrete. This construction was not required for several years to come, but as the river channel at the crossing was to be flooded by the reservoir constructed by the irrigation districts of Turlock and Modesto, the lower portion of the siphon submerged by the lake was constructed in advance of filling the reservoir.

This section, with the ends extending well above the elevation of the dam crest, is of riveted steel pipe, 9 feet 6 inches in diameter and 771 feet long. The thickness of the steel varies from ¾-inch to 9/16-inch. The interior of the pipe is lined with cement mortar 2¼ inches in thickness, leaving the net diameter 9 feet 1½ inches. The pipe is laid on bedrock and is incased in concrete from 18 inches to 2 feet in thickness. The siphon is designed to carry the entire flow of the aqueduct of 400 million gallons per day.

A camp accommodating 100 men, and a plant including tramway, bunkers, etc., were constructed on the west side of the Tuolumne River near the crossing. Excavation was started in the main channel in November, 1922, the water being diverted by means of a cofferdam around the work. This section was rushed with all possible speed. Early fall rains hampered the work and in December, when 12,000 second feet of water passed down the river, a small section of the cofferdam was washed out. After concreting this first section of pipe, the river was turned back into its channel over the pipe and a cofferdam thrown around the east channel. No unusual difficulties were encountered on the remainder of the work and the siphon was completed and tested on June 1, 1923, in time to permit the Modesto and Turlock irrigation districts to close the gates of the Don Pedro Dam and fill the reservoir for that season's irrigation.

SAN JOAQUIN SIPHON

A 45-mile steel pipe siphon is to be constructed as the last stage of the project across the San Joaquin Valley from Oakdale Portal to Tesla Portal, connecting the future Foothill and Coast Range tunnels. To carry the 400 million gallons daily, which will be released from Moccasin power house, several pipes will be constructed in the future as necessary.

COAST RANGE DIVISION

From Tesla portal to Irvington Gate House, a distance of 31 miles, a tunnel 10 feet 3 inches in diameter will be constructed through the Coast Range. It will be broken at one point by Alameda Creek, which will be crossed by a pipe line one-half mile long.

BAY DEVELOPMENT

The water which San Francisco obtains from east of the bay is now limited to about 21 million gallons daily, the capacity flow through one 36-inch pipe. A greater supply from the developed sources in Calaveras Valley, east of the bay, will be made available by the conduit across Dumbarton Strait and westward to Crystal Springs Reservoir. Work now in progress has for its object the construction of a part of the Hetch Hetchy aqueduct, which, as previously mentioned, will be used

temporarily for this purpose by the Spring Valley Water Company immediately upon its completion.

BAY CROSSING PIPE LINE

A 5-foot steel pipe line has been built, extending from a junction with the Spring Valley Water Company pipe line, near Irvington, to the east end of Pulgas Tunnel. The total length of the 5-foot pipe line is 19.4 miles, and the thickness varies from 5/16-inch to 7/16-inch. In firm and dry ground the pipe is buried, except portions crossing gullies near the west end, which are supported on steel trestles resting on concrete piers. Over the marsh lands adjacent to Dumbarton Straits, pipe is laid on timber trestles and is protected from the weather by board covering.

The contract for constructing the pipe line was awarded to the Western Pipe and Steel Company of California on May 18, 1923, for an estimated price of $2,232,000. Pipe laying was begun on October 20, 1923, and all of the pipe has now been laid.

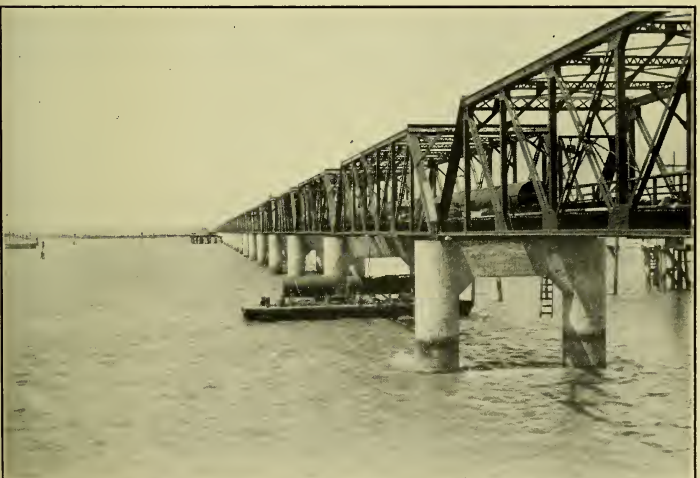
PILE TRESTLE

It was necessary to cross the marsh between Newark and Dumbarton Straits for a distance of about three miles and from the west shore of the bay for nearly one mile. A pile trestle structure was built which carries the pipe about four feet above the surface of the marsh.

Contract and specifications for this were prepared and bids received on April 30, 1924. The contract for the construction was awarded to Youdall Construction Company for the sum of $167,645.

DUMBARTON BRIDGE

Across the shallow portion of Dumbarton Strait the 5-foot diameter pipe is



Bay Development. Five-foot diameter pipe on steel bridge on concrete piers at crossing of San Francisco Bay at Dumbarton Strait

now carried on a steel bridge of 36 spans, each 105 feet long, extending from the west shore of the bay to a concrete caisson at the eastern terminal. It is designed ultimately to carry two pipes, each 6 feet 4 inches inside diameter.

The contract for the steel superstructure was awarded on August 17, 1923, to the United States Steel Products Company, and the contract for the concrete piers and caisson on April 1, 1924, to Healy-Tibbits Construction Company. Construction is still in progress.

The cost under the two contracts will be about $1,465,000.

SUBMARINE SIPHONS

Two navigable channels are crossed by the Bay Crossing Pipe Line, at Dumbarton Strait and Newark Slough. These will be crossed by cast iron pipe 42 inches inside diameter and 2 inches thick. The pipe will be laid in a trench so as to be entirely below the bottom of the bay, and will have flexible joints every 12 feet. The pipe was manufactured by the United States Cast Iron Pipe and Foundry Company. In the future, at the east terminal of the bridge, it will be feasible to sink a shaft and drive a sub-aqueous tunnel to contain the future greater pipes.

PUMP STATION

Near the west shore of Dumbarton Strait a pumping plant has been constructed to supplement the pressure at which the water is, at present, delivered to the pipe line, sufficiently to deliver it into the Crystal Springs Reservoir, 290 feet elevation, through the Pulgas Tunnel.

The station contains three centrifugal pumps, each driven by a 500 horsepower electric motor. With all three pumps operating, the capacity of the pipe line will be about 32 million gallons daily.

When the Bay Crossing Pipe Line is connected with the Hetch Hetchy Water Supply, the use of the Dumbarton pumping station will be discontinued, the gravity head available at Irvington Gate House being sufficient to give the pipe line a capacity of about 42 million gallons daily.

PULGAS TUNNEL

This tunnel, which forms the westerly end of the aqueduct from Irvington to Crystal Springs Reservoir, was completed by Grant Smith and Company in May, 1924, at a total cost of $738,429.23, or $85.11 per lineal foot. It is 8676 feet long, 10 feet 3 inches in height and width inside, and is lined with concrete throughout. All but 240 feet required timbering. Connection to the two portals is made with reinforced concrete pipe 337 feet long. A concrete lined outfall canal 906 feet long, 9 feet wide, extends from end of tunnel to the edge of the reservoir.

Plans for the future provide for extending the aqueduct through San Mateo County to Amazon Reservoir in San Francisco.

CITY RESERVOIRS

The present city reservoirs of the water company have a combined capacity of 125 million gallons, or about three days' domestic water supply, in case the mains should be broken. Prudent policy dictates that a storage of at least 1,000 million gallons should be maintained within the city limits. It is proposed that three great city reservoirs be constructed, known as the Amazon, Glen Park and Balboa Park. Land has been purchased on two of these sites.

Amazon Reservoir, near the county line, in the saddle on the north side of Geneva Avenue between Mission Street and Visitacion Valley, will be the terminal

reservoir of the Hetch Hetchy aqueduct, which will deliver water into it by gravity at elevation 250 feet. The capacity of this reservoir will be 300 million gallons or greater. A tract of land covering 55¾ acres has been selected for this reservoir site and all but 3¼ acres is already in the possession of the city.

Glen Park Reservoir site lies in a canyon just below the Twin Peaks Boulevard and above the old picnic grounds known as Glen Park. At the lower end of the valley there is an excellent bedrock site for a dam of the same general type as the Priest Regulating Dam. A dam 150 feet high will provide storage for 500 million gallons at elevation 385 feet. Over 109 acres of the 184 acres required is already under city ownership.

Balboa Park Reservoir will be constructed on a tract of land in the possession of the Spring Valley Water Company between Balboa Park and Westwood Park, north of Ocean Avenue. The site covers 41 acres. A reservoir with 200 million gallons of water, at elevation 310 feet, may be constructed here.

Glen Park and Balboa Park reservoirs will be filled by pumping from Amazon Reservoir. It has been decided that the most economical elevation at which to receive Hetch Hetchy water in San Francisco is that of the Amazon Reservoir. About 45 per cent of the total ultimate amount of water used in the city may be distributed from this latter reservoir without pumping. The elevation of Crystal Springs Reservoir, 290 feet above the sea, will not permit bringing water by gravity at an elevation materially greater than that of the Amazon Reservoir.

Quality and Quantity of Water.—The water impounded at Hetch Hetchy and Lake Eleanor is of the utmost purity and will always remain so. The total area of watershed aggregates 652 square miles, or about 420,000 acres, all of granite, ranging in elevation from 3500 feet to over 13,000 feet above sea level, and lying almost entirely within Yosemite National Park. The precipitation is mostly in the form of snow, which accumulates during the winter and spring, and whose thawing by the sun's heat reaches its maximum about June. There is no permanent, all-year residence on the entire watershed, which is inhabitable only for the three summer months.

There will be no open canal in the aqueduct, the water being conducted through pipes and tunnels for the entire distance. The water will require no filtration, aeration, chlorination, nor any treatment of any sort.

The Board of Army Engineers, in 1913, reported that there was sufficient water to supply both the reasonable demand of the bay communities and the reasonable needs of the Turlock-Modesto Irrigation District for the remainder of this century. All water measurements are made by the United States Geological Survey.

Finances.—The work was financed up to 1909 by appropriations from the general tax levy.

In November, 1908, a bond issue of $600,000 was authorized by the voters, largely to buy lands and water rights.

In January, 1910, a bond issue of $45,000,000 of 4½ per cent bonds was authorized. Construction has been carried on by these funds. The bonds sold in August to November, 1921, were converted to 5½ per cent, sustaining a discount loss of $2,980,326.55.

The operating receipts of the Hetch Hetchy railroad and power plant, aggregating $1,600,000, have been placed in a special account from which moneys have been appropriated by the Finance Committee of the Board of Supervisors to pay interest on bonds.

On October 7, 1924, a bond issue of $10,000,000 was authorized by the people by a vote of 20 to 1, to continue the aqueduct construction from Moccasin power

house to the edge of the San Joaquin Valley and to begin construction of tunnel from the westerly edge of the San Joaquin Valley to connect with the Bay Crossing pipe line at Irvington.

In about three years it will be necessary to provide an additional $23,000,000 to complete this last tunnel and construct the pipe line across the San Joaquin Valley.

The attitude of the public on the water question was well shown in the elections of 1910 and 1924, where the vote was in each case over 20 to 1 in favor of the bonds.

ESTIMATED COSTS OF VARIOUS DIVISIONS OF THE WORK

Financed from Bond Issue of 1909 and 1910, and General Fund expenditures previous to 1909.

MOUNTAIN DEVELOPMENT

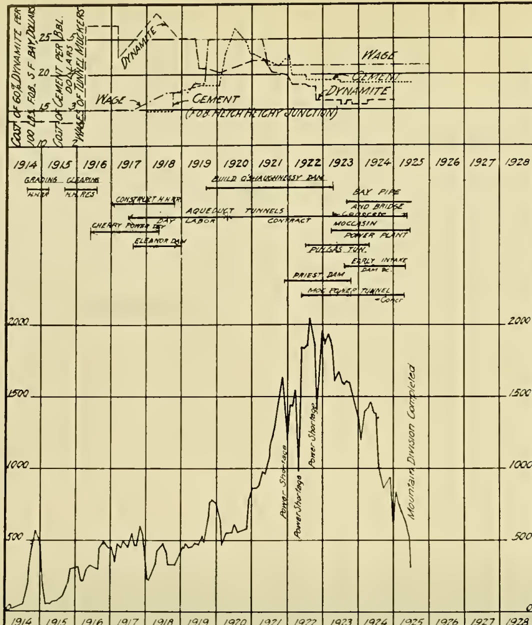
Hetch Hetchy Division		
O'Shaughnessy Dam, clearing of Hetch Hetchy Reservoir		$ 7,400,000.00
Eleanor Division		
Eleanor Dam, clearing of Lake Eleanor Reservoir		373,000.00
Mountain Division		
Early Intake Diversion Dam and spillway and headworks of aqueduct	$ 610,000.00	
Aqueduct tunnels and appurtenances, Early Intake to Priest Reservoir (18.84 miles)	10,100.000.00	
Total		10,710,000.00
Moccasin Division		
Priest Dam and Reservoir	$ 930,000.00	
Moccasin Tunnel, from Priest Reservoir to head of penstock lines	1,200,000.00	
Penstock lines	2,000,000.00	
Power House Building, dwellings, school, etc.	1,200,000.00	
Power House Machinery	1,135,000.00	
Transmission Line, Moccasin to Newark	1,623,000.00	
Total		$8,088,000.00
Foothill Division		
Red Mountain Bar Siphon		262,000.00
General, Utilities, etc., on Mountain Development		
Sawmill construction and operation	$ 556,000.00	
Lower Cherry Power System, construction and operation	1,079,000.00	
Hetch Hetchy Railroad, construction and operation	5,379,000.00	
Munn Sand Plant, Groveland Water Supply, etc.	77,000.00	
Hospital, construction and operation	221,000.00	
Miscellaneous Structures, Water Supply at Groveland	196,000.00	
Miscellaneous Roads, Trails, Camps, etc.	369,000.00	
Boarding House loss	360,000.00	
Field Engineering and Administration	381,000.00	
Total		8,618,000.00
Total, Mountain Development		$35,451,000.00

Bay Development

Riveted Steel Pipe Line, 60 inches dia	$ 2,408,000.00	
Trestle for Steel Pipe Line	198,000.00	
Submarine Pipe Lines	599,000.00	
Steel Bridge and Piers	1,560,000.00	
Gate Valves, Bay Pulgas Pumps, etc	39,000.00	
Pulgas Tunnel	757,000.00	
Field Engineering and Administration	93,000.00	
City Office Engineering and Administration	42,000.00	
Total		5,696,000.00

General

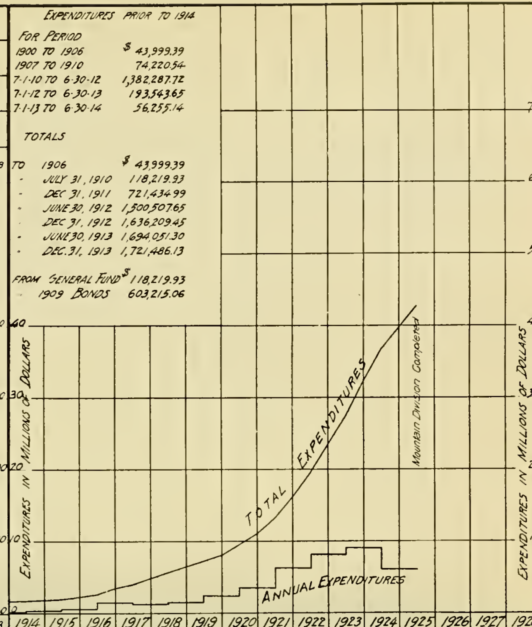
Administration, Engineering, Legal, etc	$ 1,415,000.00	
Reservoir and Watershed Lands, Water Rights, Rights-of-Way, Payments to U. S. Government, etc	2,020,000.00	
Lands and Rights-of-Way, San Joaquin Division	215,000.00	
Lands and Rights of Way, Transmission Line	117,000.00	
Lands and Rights-of-Way, Bay Development	221,000.00	
Miscellaneous	322,000.00	
Total		4,310,000.00
Total Expenditures		$45,457,000.00
Less credit for receipts from operation of Hetch Hetchy Railroad, Lower Cherry Power System, lumber sales, etc		1,907,000.00
Net total expenditures after deducting credits, which may be still further reduced on final accounting by salvage value of equipment now on hand		$43,550,000.00



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA

UPPER: GRAPHIC RECORDS OF COSTS OF LABOR AND MATERIALS.
LOWER: GRAPHIC RECORD OF NUMBER OF MEN EMPLOYED.
NOTE: EMPLOYEES IN THE SAN FRANCISCO OFFICES ARE NOT INCLUDED IN THE COUNT.

DEPARTMENT OF PUBLIC WORKS. APPROVED M.M. O'Shaughnessy CITY ENGINEER
BY L.B.C. TRACED L.B.C. CHECKED
SCALE DATE Oct 15 1925 A-302



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA

GRAPHIC RECORDS OF
ANNUAL AND TOTAL EXPENDITURES.

DEPARTMENT OF PUBLIC WORKS. APPROVED M.M. O'Shaughnessy CITY ENGINEER
BY L.B.C. TRACED L.B.C. CHECKED
SCALE DATE Oct 15 1925 A-303

STATISTICS OF HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO

I. HETCH HETCHY AND LAKE ELEANOR RESERVOIRS

	—Hetch Hetchy Reservoir—		——Lake Eleanor——	
	Initial	Ultimate	Present	Ultimate
Area of watershed, square miles	459	459	79	183*
Capacity of reservoir, millions of gallons	67,000	113,500	9,000†	71,000†
Acre feet	206,000	348,500	28,000	218,000
Water surface area, acres	1,600	1,940	948	
Square miles	2.5	3	1.5	
Elevation of roadway on dam, feet	3,726.5	3,812	4,661	4,825
Elevation of spillway crest, feet	3,719.75	3,800	4,660‡	4,810
Length of reservoir, miles	7.5	8	3.1	3.2
Width of reservoir, maximum, miles	0.65	0.7	1.0	1.1
Width of reservoir, average, miles	0.33	0.38	0.5	0.7
Depth of reservoir from spillway crest:				
Maximum, feet	220	300	60†	210†
Dam:				
Type of dam	Concrete, gravity section, arched in plan		Reinforced concrete buttressed arch	Rock fill with concrete facing
Total length on crest, feet	605	900	1,260	2,000
Height of crest above stream level, feet	226	312	60	225
Depth from stream level to bedrock, at toe of dam, maximum, feet	(Roadway) 118	(Roadway) 118	Stream bed is solid rock	(Roadway)
Total height of dam, above bedrock, feet	344	430	60	225
Width at top, feet	15	25		25
Width at base, maximum, feet	298	298		
Volume of masonry, cubic yards	398,516	625,000	11,640	
Type of spillway	Siphon	Channel around end of dam	Overflow	Channel around end of dam

*—Includes Cherry watershed above proposed diversion.
†—Lake Eleanor depths and capacities do not include the portion of original lake not available for draft.
‡—With flashboards in place; 4,655 without flashboards.

II. RESERVOIRS FOR FUTURE DEVELOPMENT

	Poopenaut Valley	Cherry Valley	Lake Vernon	Huckleberry Lake	Emigrant Lake
Area of watershed, square miles	473*	114†	40‡	17†	11†
Capacity of reservoir:					
Millions of gallons	10,000	18,500	16,600	17,000	4,600
Acre feet	31,000	57,000	51,000	52,200	14,250
Water surface area:					
Acres	383	1,150	640	800	320
Square miles	0.6	1.8	1.0	1.25	0.5
Elevation of spillway crest, feet	3,468.5	4,550	6,630	7,700	8,700
Length of reservoir, miles	2.3	3.4	2	4	2
Width of reservoir:					
Maximum, miles	0.55	0.8	0.7	0.5	0.3
Average, miles	0.45	0.53	0.5	0.3	0.25
Depth of reservoir:					
Maximum, feet	160	150	105	100	60
Average, feet	81	50	80	65	45
Type of dam	Concrete gravity section	Rock fill	Rock fill or Eleanor type	Rock fill	Rock fill
Length of dam, feet	370	1,060	2,000	520	420

*—Includes Hetch Hetchy watershed.
†—Cherry Valley watershed includes watersheds of Huckleberry and Emigrant Lakes.
‡—Included in Hetch Hetchy watershed.

III. POWER DEVELOPMENT POSSIBILITIES

Location of plant	Early Intake	Moccasin Creek		Early Intake	North Mountain
Source of water supply	Cherry River	Hetch Hetchy and Lake Eleanor		Hetch Hetchy	Lake Eleanor
Aqueduct, type	Flume, canal and tunnel	Pressure tunnel		Pressure tunnel	Canal and tunnel
Aqueduct length, miles (not including pressure pipes)	3.3	19.8		11	7.6
Aqueduct capacity, sec. ft.	200	620		620	200
Forebay, type	Large flume	Reservoir		None	None
Forebay capacity:					
Gallons	1,500,000	800,000,000			
Acre feet	4.6	2,350			
Pressure pipes:		Present	Proposed		
Length, feet	530	5,580	5,580	2,500	5,700
Number of pipes	1	2	3		
Diameter of pipes	3′6″	104″-54″	104″-54″		
Gross drop, feet	345	1,316	1,316	1,100	2,000
Power plant:					
24-hr. average capacity—					
K. W.	3,000	52,500	52,500	42,000	24,000
H. P.	4,000	70,000	70,000	56,000	32,000
Number of generators	3	4	6		
Capacity each machine, K. W.	1,100	17,500	17,500		
Total installed capacity—					
K. W.	3,300	70,000	105,000		
H. P.	4,400	94,000	141,000		

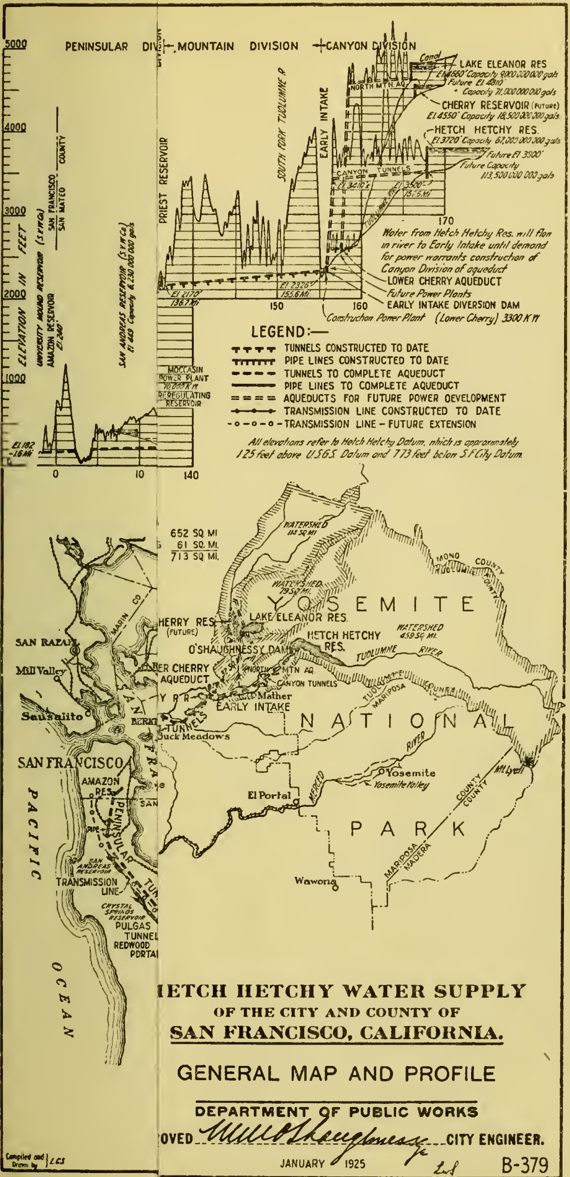
Note: Development of Huckleberry and Emigrant Lakes as reservoirs will make available additional power, the amount of which has not yet been determined.

Jan. 8, 1900	New Charter in effect.
March 26, 1900	Solicitation of offers of sale of water supplies to City.
Aug. 12, 1901	City Engineer recommends Tuolumne River.
July 29, 1901	Appropriations made on water at Hetch Hetchy and Lake Eleanor by Jas. D. Phelan.
Oct. 16, 1901	Filings of same at Stockton Land Office.
Jan. 20, 1903	Phelan's applications denied by Secretary of Interior Hitchcock.
February, 1903	Petition for rehearing, by Franklin K. Lane, City Attorney.
Feb. 20, 1903	Filings assigned to City.
Dec. 22, 1903	Application again denied by Secretary of Interior.
May 11, 1908	Original applications approved by Secretary of Interior Garfield.
Nov. 12, 1908	Special election authorized construction of Tuolumne System and issue of $600,000 of bonds, to buy lands, etc.
Jan. 14, 1910	Bond election, $45,000,000 bonds authorized by vote of 20 to 1.
Feb. 25, 1910	Order to show cause why Hetch Hetchy should not be eliminated: Secretary of Interior Ballinger.
May 12, 1910	Secretary of Interior requested Secretary of War to appoint Board of Army Engineers to act as Advisory Board.
May 18, 1910	Board appointed.
July, 1912	"Freeman Plan" of Hetch Hetchy development, published and submitted to Army Board.
Sept. 1, 1912	M. M. O'Shaughnessy appointed City Engineer.
Nov. 25 to 30, 1912	Hearings before Secretary of Interior Fisher, attended by Mayor, City Engineer, City Attorney and consulting engineers.
Feb. 9, 1913	Army Board report upholds selection of Tuolumne River as $20,000,000 cheaper than any other system and having greatest power possibilities.
March 3, 1913	Conference: City Engineer with Secretary Fisher.
June 25 to July 7, 1913	Hearings by committee on the Public Lands, House of Representatives.
Dec. 19, 1913	Hetch Hetchy Grant, or "Raker Bill," signed by President Wilson.
July 8, 1914	Bids received by Board of Public Works for Contract No. 1, for constructing a road from Hog Ranch (now Mather) to Hetch Hetchy.
July 21, 1915	Began manufacture of lumber at Canyon Ranch.
September, 1915	Began construction of camp buildings at Hetch Hetchy, clearing of Hetch Hetchy Reservoir site, and construction of Diversion Tunnel.
Nov. 24, 1915	Bids received for construction of Hetch Hetchy Railroad.
Aug. 9, 1916	Bids received for "Drifting Tunnels, Lower Cherry Aqueduct," already begun by day labor.
October, 1917	Hetch Hetchy Railroad operation begun.
May 6, 1918	Lower Cherry Power House began operation.
Aug. 1, 1919	Contract awarded for construction of Hetch Hetchy Dam.
May 3, 1920	Contract awarded for construction of Aqueduct Tunnels in Mountain Division, this work having been carried on so far by day labor.
Fall, 1921	Work begun on Priest Dam.
Fall, 1921	Work begun on Moccasin Power House.
June 23, 1922	Contract awarded for construction of Pulgas Tunnel.
May 18, 1923	Contract awarded for construction of Bay Crossing Pipe Line.
Oct. 7, 1924	Special Election, $10,000,000 bonds authorized to construct Foothill Tunnels and begin Coast Range Tunnels, vote 20 to 1.
Aug. 14, 1925	Delivery of power began from Moccasin Power Plant.

ELEVATIONS OF VARIOUS POINTS ON WATER PROJECT

13,090 ft. Summit of Mt. Lyell, highest point on watershed.
4,825 ft. Crest of future Lake Eleanor Dam.
4,810 ft. High water, Lake Eleanor Dam.
4,660 ft. Top of present Lake Eleanor Dam.
4,590 ft. Creek bed at Lake Eleanor Dam.
3,812 ft. Crest of future O'Shaughnessy Dam.
3,726.5 ft. Crest of present O'Shaughnessy Dam.
3,500 ft. River bed at O'Shaughnessy Dam.
3,382 ft. Lowest point of foundation, O'Shaughnessy Dam.
2,346 ft. Normal water surface, Early Intake Diversion Dam.
2,326 ft. Floor of tunnel, Early Intake Diversion Dam.
2,240 ft. High water, Priest Regulating Reservoir.
2,170 ft. Floor of tunnel at Priest Portal of 18.8-mile tunnel.
2,145 ft. Floor of inlet of Moccasin Power Tunnel.
924 ft. Nozzles of Moccasin Power House.
888 ft. Floor of Foothill Division Tunnel at Moccasin Creek.
741.6 ft. Floor of Foothill Division Tunnel at Oakdale Portal.
360 ft. Floor of Mt. Diablo Range Tunnel at Tesla Portal.
321 ft. Floor of Mt. Diablo Range Tunnel at Irvington Gate House.
290.5 ft. Floor of Pulgas Tunnel at Redwood Portal.
250 ft. Water surface, Amazon Reservoir, San Francisco.

THE JAMES H. BARRY CO.
1122 MISSION STREET
SAN FRANCISCO, CALIF.



HETCH HETCHY WATER SUPPLY

OF THE CITY AND COUNTY OF

SAN FRANCISCO, CALIFORNIA.

GENERAL MAP AND PROFILE

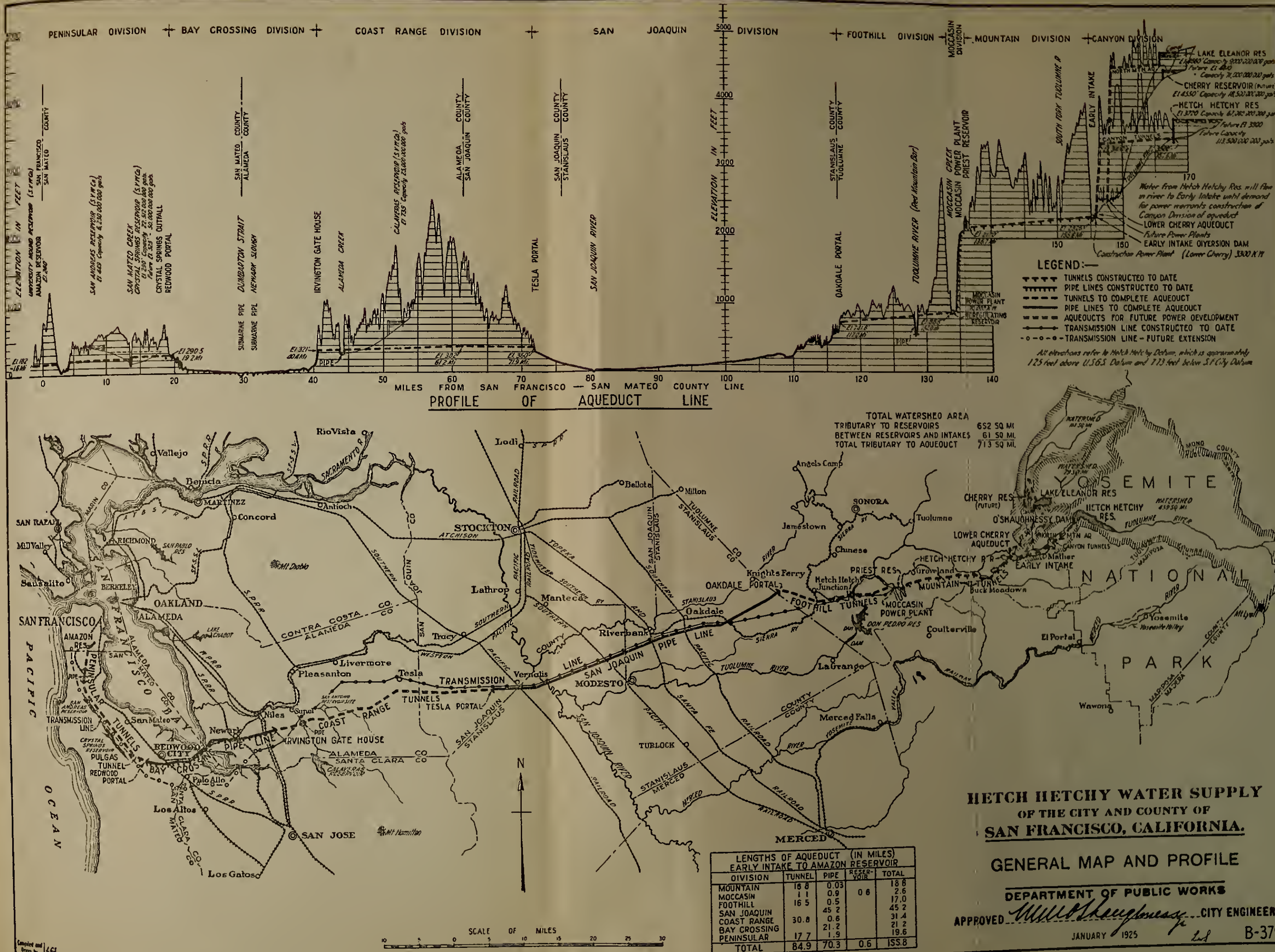
DEPARTMENT OF PUBLIC WORKS

APPROVED M M O'Shaughnessy CITY ENGINEER.

JANUARY 1925

B-379

Compiled and Drawn by LCS



LENGTHS OF AQUEDUCT (IN MILES) EARLY INTAKE TO AMAZON RESERVOIR				
DIVISION	TUNNEL	PIPE	RESERVOIR	TOTAL
MOUNTAIN	18 8	0.03		18 8
MOCCASIN	1 1	0.9	0 6	2.6
FOOTHILL	16 5	0.5		17.0
SAN JOAQUIN		45 2		45 2
COAST RANGE	30.8	0.6		31 4
BAY CROSSING		21.2		21 2
PENINSULAR	17 7	1.9		19.6
TOTAL	84.9	70.3	0.6	155.8

HETCH HETCHY WATER SUPPLY
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